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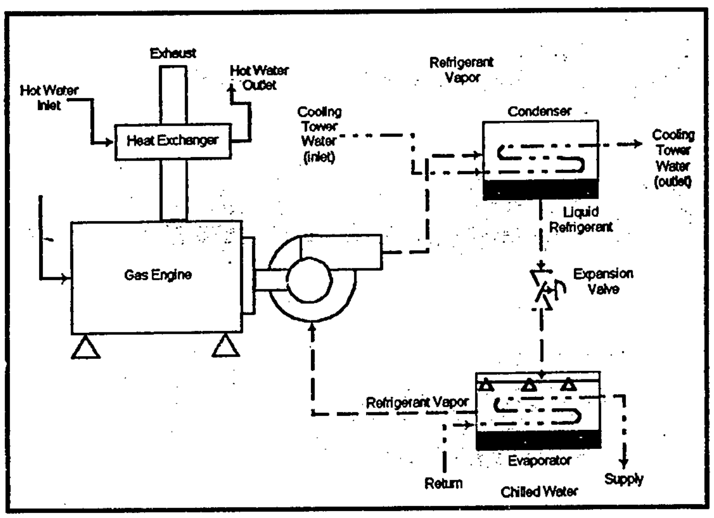
Performance Analysis of Natural Gas Cooling Technology at Air Force Bases

Youngstown-Warren ARS and Warner-Robins AFB, Fiscal Year 1999

William T. Brown, III



High-efficiency gas-fired cooling equipment is readily available for commercial, institutional, and industrial facilities. Natural gas engine-driven chillers have higher coefficients of performance than any other natural gas cooling system, and can serve as energy efficient alternatives for new electric chillers. This study monitored the performance of natural gas cooling technologies operating at two Air Force bases during the fiscal year 1999 cooling season and compared the actual performance data to theoretical values.

Energy and demand cost analyses were performed to compare each natural gas cooling technology with the energy and demand costs of old and new electric chillers. The study determined that, at the monitored bases, the costs for the natural gas used by the engine-driven chillers were lower than electrical costs used by old and new electric chillers, resulting in an energy cost savings.

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Foreword

This study was conducted for the Headquarters, Air Force Civil Engineer Support Agency (HQ AFCESA), under Military Interdepartmental Purchase Request (MIPR) No. N28FY97000081, Work Unit VR7, "Natural Gas Cooling Technology Program." The technical monitor was Freddie Beason, and the contract monitor was Rich Bauman, AFCESA/CESM.

The work was performed by the Energy Branch (CF-E) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was William T. Brown, III. Larry Windingland is Chief, CF-E, and Dr. L. Michael Golish is Chief, CF. The technical editor was William J. Wolfe, Information Technology Laboratory - CERL.

The Director of CERL is Dr. Michael J. O'Connor.

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1 Introduction

Background

Under the Department of Defense (DOD) Natural Gas Cooling Demonstration Program, four Air Force bases have four natural gas engine-driven chiller systems currently in operation: Davis-Monthan Air Force Base (AFB), AZ; Utah Air National Guard (ANG), UT; Youngstown-Warren Air Reserve Station (ARS), OH; and Warner-Robins AFB, GA. Natural gas-fired cooling technology was chosen for these locations for the same reasons that natural gas cooling has become viable in the commercial market:

- the availability of a new generation of more efficient and reliable gas cooling products
- low natural gas prices
- the desire to cut energy costs and eliminate electric peak demand charges
- the desire to bring operating costs down
- the responsiveness to environmental calls to switch to cleaner, chlorofluorocarbon (CFC) free technologies
- the need to improve indoor air quality, economically
- the responsiveness to political calls to use an abundant fuel such as natural gas, 95 percent of which is produced domestically.

Currently, high-efficiency gas-fired cooling equipment is readily available for commercial facilities including hotels, office buildings, warehouses, supermarkets, and retail outlets; institutions including hospitals, nursing homes, and schools; and industrial facilities (American Gas Cooling Center, April 1996, p 7). The three types of natural gas cooling equipment presently on the market are: (1) natural gas engine-driven chillers, (2) absorption cooling systems, and (3) desiccant cooling systems. Of the three types, gas engine-driven chillers have the highest coefficients of performance (COPs) and, in many parts of the United States, have demonstrated the lowest total operating costs.

Engine driven chillers offer important advantages over electric hermetic and electric open drive chillers. The engine-driven chiller (Figure 1) is comprised of a reciprocating engine coupled through a gearbox to an open drive chiller. The electric motor of a hermetic chiller is totally enclosed within a compressor housing, and is cooled by the refrigerant.

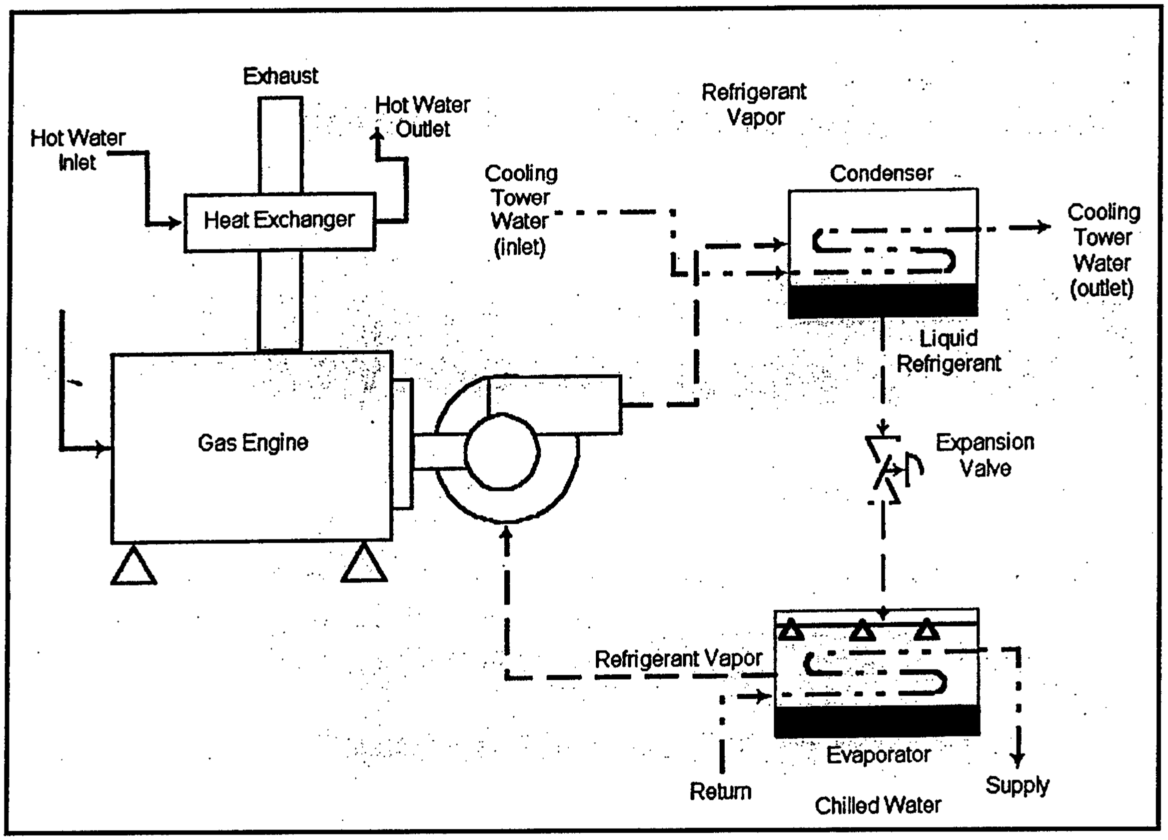

Figure 1. Gas engine-driven chiller.

The additional heat load from the motor, when transferred to the refrigerant, adds 3 to 6 percent in energy consumption. In contrast, with an engine-driven chiller, most of the heat that is generated by the engine to drive the compressor can be recovered from the engine's jacket cooling and exhaust systems. This recoverable engine heat does not have to be discharged to the environment through the chiller's condenser (American Gas Cooling Center, April 1996, p 3).

Natural gas engine-driven chillers use three major types of compressors:

1. *Centrifugal* compressors are available for applications over 400 tons and have been built for systems up to 6,000 tons.
2. *Screw* compressors are used for applications from 100 to 4,000 tons.
3. *Reciprocating* compressors are typically applied to engine-driven systems requiring less than 200 tons (American Gas Cooling Center, April 1996, p 4).

Typical COPs of natural gas engine-driven chillers at full load range from 1.2 to 2.0 with no heat recovery, 1.5 to 2.25 with jacket water heat recovery, and from 1.7 to 2.4 with both jacket water and exhaust heat recovery. Heat recovery from the jacket coolant and exhaust gas will boost overall energy utilization (American Gas Cooling Center, April 1996, p 7).

On the other hand, since the majority of facilities in the United States have electric-driven chillers, personnel are already familiar with the maintenance procedures for electric-driven units. The introduction of gas cooling technology into these facilities will require retraining of personnel or the purchase of maintenance agreements. The costs of these agreements are usually a function of the chiller capacity. (Such agreements are not exclusive to gas engine-driven chillers and can also be purchased for electric-driven chillers.)

The maintenance cost of gas engine-driven chillers is somewhat more expensive than that of an electric-driven or absorption chillers, or desiccant dehumidifying systems. Annual maintenance costs are based on the annual equivalent full load hours of operation, maintenance costs, and chiller capacity. The maintenance costs of gas engine-driven chillers are approximately 1.5 to 3 times higher than their electric counterparts; the cost of absorption units and desiccant dehumidifying systems falling somewhere in between (Pedersen and Brown 1997).

The Construction Engineering Research Laboratory (CERL) was tasked with monitoring the performance of the natural gas technologies at each installation during two consecutive cooling seasons, and with comparing the actual performance data to theoretical values. As part of this monitoring effort, energy and demand cost analyses were performed to compare natural gas cooling technologies with the energy and demand costs of old and new electric chillers.

Objective

The overall objective of this study was to monitor and report on the performance of natural gas cooling technologies at Air Force bases during the fiscal year (FY) 1999 cooling season. Specific objectives of this part of the monitoring effort were to perform energy and demand cost analyses to compare natural gas cooling technology at each Air Force base with the energy and demand costs of old and new electric chillers. This study is a follow-up to CERL Technical Report 99/14, *Performance Analysis of Natural Gas Cooling Technology at Air Force Bases.*

Approach

CERL representatives were available to supervise and evaluate the acceptance testing results for the installed systems. Monitoring equipment was specified for each facility to record data for either 1 or 2 years. A Hayes-compatible modem was connected to a host computer workstation (at CERL) to enable communication between CERL and the remote computer (at the base). Certain types of communications software (including HyperTerminal, SYNERNET™, METASYS™, ModemPro™, net files, etc.) were required to be installed on the host computer for compatibility with the appropriate remote computer workstation. The phone numbers and login access parameters for each of the remote sites were obtained during the acceptance testing visits. Technical and economic aspects of system performance were monitored remotely. Collected data were analyzed to evaluate the effectiveness of gas equipment at each demonstration site.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for International System of Units (SI) is provided below.

SI conversion factors					
1 in.	=	2.54 cm	1 cu ft	=	0.028 m^3
1 ft	=	0.305 m	1 cu yd	=	0.764 m^3
1 yd	=	0.9144 m	1 gal	=	3.78 L
1 sq in.	=	6.452 cm^2	1 lb	=	0.453 kg
1 sq ft	=	0.093 m^2	°F	=	(°C x 1.8) + 32
1 sq yd	=	0.836 m^2	1 ton (refrigeration)	=	3.516 kW
1 cu in.	=	16.39 cm^3			

2 Review of Natural Gas Cooling Performance Analysis

Data Points Required to Monitor for Performance Analysis

Data points used in monitoring the operation of chillers are best sampled every 15 minutes. The following data points are required to obtain a proper performance analysis for natural gas cooling equipment:

- chilled water supply (CHWS) temperature
- chilled water return (CHWR) temperature
- chilled water (CHW) flow in gallons per minute (gpm)
- natural gas flow rate in standard cubic feet per hour (SCFH).

The CHWS temperature, CHWR temperature, and CHW flow are used to calculate the chiller capacity in tons. Once the tons are calculated, the COP of the chiller can be calculated, given the flow rate and higher heating value (HHV) of natural gas (Brown 1998, p 5).

Performance Analysis Calculations

Chiller Capacity

The capacity of a chiller, in tons, is determined by the following equation:

$$\text{Tons} = \frac{(\text{CHW Flow}) * (\text{CHWR Temp} - \text{CHWS Temp})}{24} \qquad \textbf{Eq 1}$$

where CHWR Temp and CHWS Temp are expressed in degrees Fahrenheit (°F), and CHW Flow in gpm.

Coefficient of Performance

The COP of the chiller is the standard calculation for rating the performance of cooling equipment. COPs for engine driven chillers can be determined using the following equation:

$$COP = \frac{\text{Tons} * 12{,}000 \text{ BTU/ton} - \text{hr}}{\text{Natural Gas Flow (in SCFH)} * \text{HHV}} \quad \text{Eq 2}$$

where HHV is determined from a base gas bill.

Energy and Demand Cost Analysis Calculations

Data was collected from each facility to indicate the peak tonnage produced by the engine-driven chillers each month and the number of hours at various average loads during the entire monitoring period. Peak monthly tonnage information is necessary to estimate the demand charges that would result if electric motor-driven chillers are used instead of natural gas engine-driven chillers. Load duration information is required to estimate energy costs.

If no ratchet is applied:

$$\text{Demand Cost} = \left(\frac{\text{Tons}_{actual}}{\text{Tons}_{design}}\right) * \left(\text{Tons}_{actual} * \left(\frac{\text{kW}}{\text{ton}}\right)_{new}\right)_{max} * \text{Demand Charge} \quad \text{Eq 3}$$

where:

Tons_{actual} = Monthly peak load

Tons_{design} = Full-load capacity of the gas engine-driven chiller

$(\text{kW/ton})_{new}$ = Efficiency of new electric chiller at full load

$(\text{Tons}_{actual} * (\text{kW/ton})_{new})_{max}$ = Maximum product of monthly peak load and efficiency of new electric chiller over selected monitoring period.

If a ratchet is applied, and the load ratio ($\text{Tons}_{actual}/\text{Tons}_{design}$) is greater than the ratchet percentage:

$$\text{Demand Cost} = \text{Tons}_{actual} * \left(\frac{\text{kW}}{\text{ton}}\right)_{new} * \text{Demand Charge} \quad \text{Eq 4}$$

If a ratchet is applied, and the load ratio ($Tons_{actual}/Tons_{design}$) is less than the ratchet percentage:

$$\text{Demand Cost} = \left(\frac{\%\,\text{Ratchet}}{100}\right) * \left(\frac{\text{kW}}{\text{ton}}\right)_{new} * \text{Tons}_{design} * \text{Demand Charge} \qquad \textbf{Eq 5}$$

Load duration information includes the number of hours a chiller operates within specified ton ranges. Depending on how the ton ranges are grouped, the ton-hours would be computed as:

$$\text{Ton-Hours} = \sum_{i=1}^{n} (\text{Avg Ton Range} * \text{Hours in Ton Range}) \qquad \textbf{Eq 6}$$

The energy cost would then be computed by the following equation:

$$\text{Energy Cost} = \left(\frac{\text{kW}}{\text{ton}}\right)_{new} * \text{Ton-Hours} * \text{Energy Charge} \qquad \textbf{Eq 7}$$

3 Results of Performance Analysis

Overview of Air Force Facilities Monitored

Youngstown-Warren ARS, OH

Youngstown-Warren ARS currently has one, 140-ton, NAPPS gas engine-driven water-cooled chiller package in operation carrying a refrigerant mixture composed of water and 40 percent ethylene glycol concentration. The chiller provides service to Building 407 (Composite Reserve Forces Operational Training Facility). Data points monitored during its operation are collected using the Johnson Controls METASYS™ Companion system. The chiller has the following design parameters: 1.34 full-load COP, 1.62 COP at 93.64 tons, 1.65 COP at 88.85 tons, 1.79 COP at 84.78 tons, 1.73 COP at 79.44 tons, 44 °F chilled water supply temperature, 54 °F chilled water return temperature, and 330 gpm of chilled water flow. The HHV is 991 Btu/SCF. The Youngstown-Warren ARS Point of Contact (POC) is George Mocker, tel.: (330) 609-1063.

Warner-Robins AFB, GA

Warner-Robins AFB currently has two, 1310-ton, R-134A York-Caterpillar gas engine-driven water-cooled chillers in operation. The chillers, named Chiller #5 and Chiller #6, respectively, are located at the central energy plant, Building 177. Commissioning of the chillers was completed in July 1999. Data points monitored during its operation are collected using the Johnson Controls METASYS™ Person Machine Interface (PMI) workstation system. The chiller has the following design parameters: 1.83 full-load COP, 2.27 COP at 982.5 tons, 2.53 COP at 655 tons, 1.88 COP at 327.5 tons, 43 °F chilled water supply temperature, 53 °F chilled water return temperature, and 3144 gpm of chilled water flow. The HHV is 1010 Btu/SCF. The Warner-Robins AFB POC is Ray Tuten, tel.: (912) 926-3533, ext. 136.

Comparison of Design and Actual Values

Results from Youngstown-Warren ARS

Data for the 140-ton, gas engine-driven chillers was acquired for the months of May through August 1999. Based on part-load COPs at 79.44 tons, 84.78 tons, 88.85 tons, and 93.64 tons, the natural gas flow estimates for different chiller capacities can be determined by interpolation. During this period, the chiller used an estimate of 643 MBtu of natural gas. The unit cost of natural gas is $4.34/MBtu. Based on the foregoing, the cost for the natural gas by the 140-ton chiller would be $4.34/MBtu x 643 MBtu = $2,791. Information from the base indicates there is a charge of $18.36/kW for demand (with no ratchet applied), and an energy charge of $0.037/kWh. Table 1 shows the demand charges for the chiller in Building 407 with a full load efficiency of 0.7 kW/ton for a new electric chiller. Figure 2 shows the peak tonnages produced by the engine-driven chillers each month. From Table 1, the total demand charges for the period = $1,915. Table 2 shows the results of the ton-hour calculations for the entire monitoring period for the chiller.

Table 1. Youngstown-Warren ARS chiller results: demand charges.

Month	Peak Load	COP	When Peak Occurred		Demand Cost
			Date	Time	
May 99	58.45	1.45	5/4/99	15:16	$466
Jun 99	86.79	1.72	6/15/99	11:41	$692
Jul 99	64.47	1.54	7/19/99	18:11	$514
Aug 99	30.51	0.93	8/31/99	21:26	$243

Using the full load efficiency of 0.7 kW/ton and the appropriate energy charge, the energy cost is:

Energy cost = 0.7 kW/ton x 42,216.57 ton-hr x $0.037/kWh = $1,093

The total electrical cost for a new electric chiller for the period would be:

Building 407 Chiller: $1,915 + $1,093 = $3,008

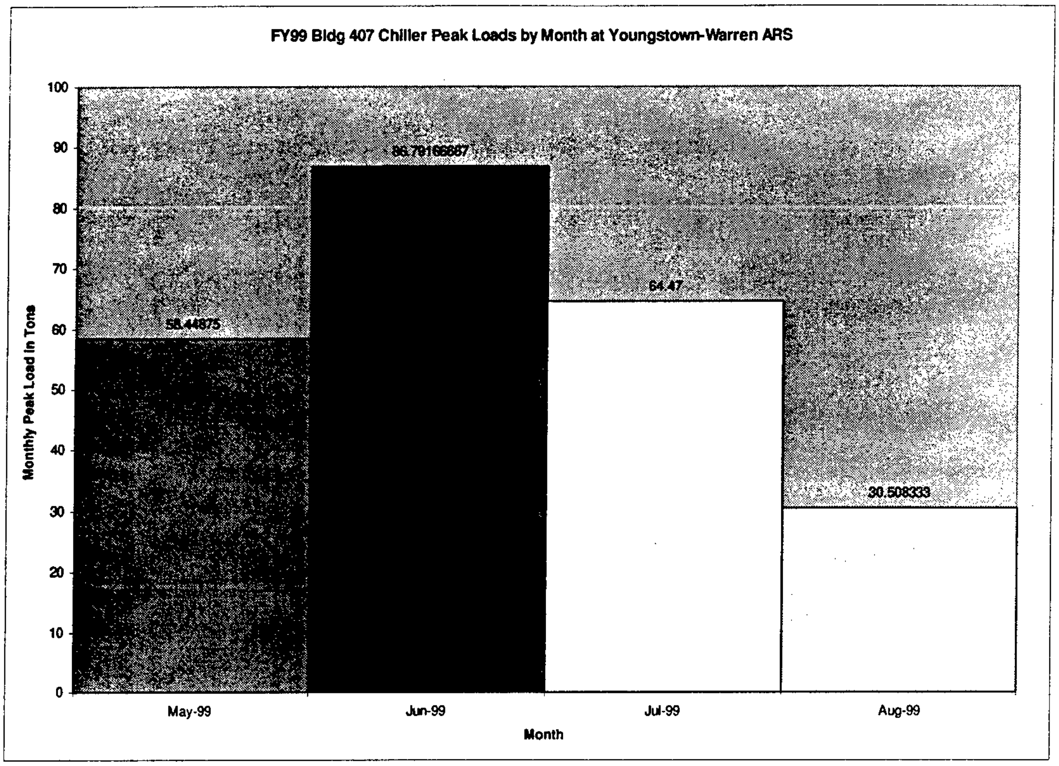

Figure 2. Youngstown-Warren ARS chiller peak loads.

Table 2. Youngstown-Warren ARS Building 407 chiller ton-hours by ton range.

Ton Range	Hours	Ton-Hours
4.375	200.75	878.28
13.125	375.00	4,921.88
21.875	432.75	9,466.41
30.625	312.25	9,562.66
39.375	294.75	11,605.78
48.125	101.00	4,860.63
56.875	11.50	654.06
65.625	3.75	246.09
74.375	0.00	0.00
83.125	0.25	20.78
91.875	0.00	0.00
100.625	0.00	0.00
109.375	0.00	0.00
118.125	0.00	0.00
126.875	0.00	0.00
135.625	0.00	0.00
Total	**1,732.00**	**42,216.57**

The efficiency of the old electric chiller at the central plant was 0.8 kW/ton. Regardless of load, the demand costs would then be:

May 99:	58.45 tons x 0.8 kW/ton x $18.36/kW	= $ 859
Jun 99:	86.79 tons x 0.8 kW/ton x $18.36/kW	= $1,275
Jul 99:	64.47 tons x 0.8 kW/ton x $18.36/kW	= $ 947
Aug 99:	30.51 tons x 0.8 kW/ton x $18.36/kW	= $ 448

The total demand costs for each chiller during the monitoring period would be $3,529.

The electrical energy cost would then be:

Energy cost = 0.8 kW/ton x 42,216.57 ton-hr x $0.037/kWh = $1,250

If the old electric chiller were used, the total electrical cost would then be:

Building 407 Chiller: $3,529 + $1,250 = $4,779

Table 3 summarizes the costs for Youngstown-Warren ARS. The life cycle economics for Youngstown-Warren ARS is detailed in the Appendix, and includes parasitic electrical requirements for the chiller.

Table 3. Cost comparison of old vs. new chillers, Youngstown-Warren ARS.

Chiller	Cost
Old electric chiller	$4,779
New electric chiller	$3,008
New gas chiller	$2,791 (estimate)

Results from Warner-Robins AFB

Data for the two, 1310-ton, gas engine-driven chillers was acquired for the months of July through August 1999. Based on the full-load COP at 1310 tons and part-load COPs at 327.5 tons, 655 tons, and 982.5 tons, the natural gas flow estimates for different chiller capacities can be determined by interpolation. During this period, Chiller #5 used July and August natural gas estimates of 302 MBtu and 308 MBtu, respectively. Likewise, Chiller #6 used July and August natural gas estimates of 78 MBtu and 1,699 MBtu, respectively. It should also be noted that the month of July covered only the period from 29 to 31 July, since the remote monitoring capabilities at CERL were finally established during that time. The unit costs of natural gas for July and August were $2.47/MBtu and $2.52/MBtu, respectively. Based on the foregoing, the cost for the natural gas used by Chiller #5 would be ($2.47/MBtu x 302 MBtu) + ($2.52/MBtu x 308 MBtu) = $1,522, and the cost for the natural gas used by Chiller #6 would be

($2.47/MBtu x 78 MBtu) + ($2.52/MBtu x 1,699 MBtu) = $4,474. Information from the base indicates there is an energy charge of $0.03552/kWh for the month of July and an energy charge of $0.04932/kWh for the month of August (due to real-time pricing). There are no demand charges applied at the base. Tables 4 and 5 show the demand charges for Chillers #5 and #6 to be zero. Figures 3 and 4 show the peak tonnages produced by the engine-driven chillers each month. Tables 6 and 7 show the results of the ton-hour calculations for the entire monitoring period for the chiller.

Table 4. Warner-Robins AFB Chiller #5 results.

Month	Peak Load	COP	When Peak Occurred		Demand Cost
			Date	Time	
Jul 99	1258.75	1.87	7/29/99	19:00	$0.00
Aug 99	1128.63	2.02	8/12/99	15:30	$0.00

Table 5. Warner-Robins AFB Chiller #6 results.

Month	Peak Load	COP	When Peak Occurred		Demand Cost
			Date	Time	
Jul 99	1247.2	1.89	7/29/99	18:00	$0.00
Aug 99	1232.18	1.90	8/17/99	16:30	$0.00

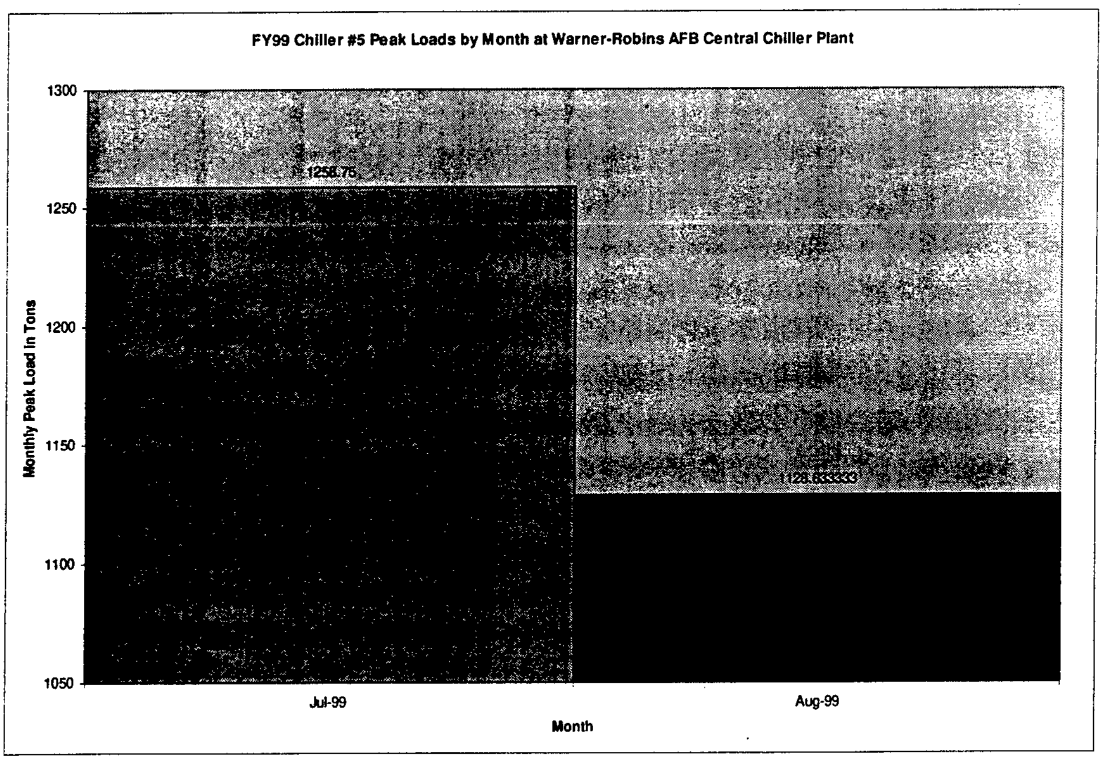

Figure 3. Warner-Robins AFB Chiller #5 peak loads.

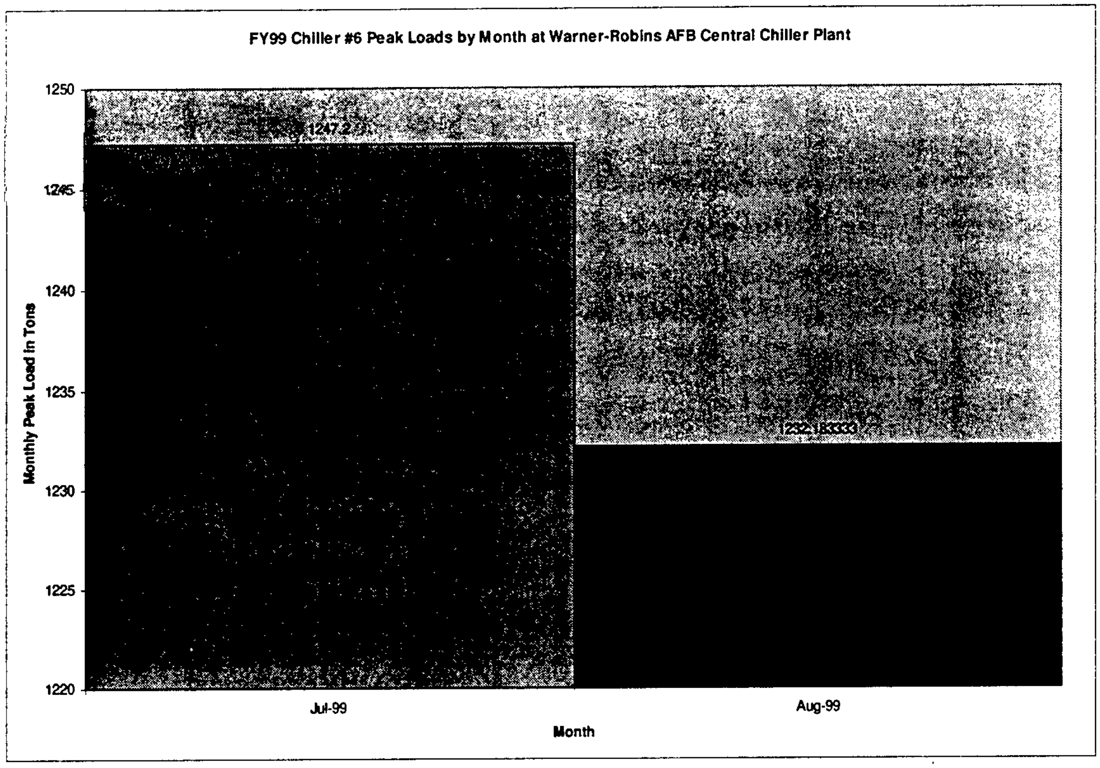

Figure 4. Warner-Robins AFB Chiller #6 peak loads.

Table 6. Warner-Robins AFB Chiller #5 ton-hours by ton range.

Ton Range	Jul 99		Aug 99	
	Hours	Ton-Hours	Hours	Ton-Hours
16.375	0.00	0.00	20.50	335.69
49.125	0.00	0.00	0.00	0.00
81.875	0.00	0.00	0.00	0.00
114.625	0.00	0.00	0.50	57.31
147.375	0.00	0.00	0.00	0.00
180.125	0.00	0.00	0.00	0.00
212.875	0.00	0.00	0.00	0.00
245.625	0.00	0.00	0.00	0.00
278.375	0.00	0.00	0.00	0.00
311.125	0.00	0.00	0.00	0.00
343.875	0.00	0.00	0.00	0.00
376.625	0.00	0.00	0.00	0.00
409.375	0.00	0.00	0.00	0.00
442.125	0.00	0.00	0.00	0.00
474.875	0.00	0.00	0.00	0.00
507.625	0.00	0.00	0.00	0.00
540.375	0.00	0.00	0.00	0.00
573.125	0.00	0.00	0.00	0.00
605.875	0.00	0.00	0.00	0.00
638.625	0.00	0.00	0.00	0.00

Ton Range	Jul 99		Aug 99	
	Hours	Ton-Hours	Hours	Ton-Hours
671.375	0.00	0.00	0.50	335.69
704.125	0.00	0.00	3.00	2,112.38
736.875	0.00	0.00	3.50	2,579.06
769.625	0.00	0.00	8.00	6,157.00
802.375	0.00	0.00	6.50	5,215.44
835.125	0.50	417.56	5.00	4,175.63
867.875	3.50	3,037.56	2.50	2,169.69
900.625	3.50	3,152.19	7.50	6,754.69
933.375	9.00	8,400.38	8.50	7,933.69
966.125	9.50	9,178.19	7.50	7,245.94
998.875	11.50	11,487.06	4.00	3,995.50
1031.625	9.00	9,284.63	2.00	2,063.25
1064.375	4.00	4,257.50	2.50	2,660.94
1097.125	1.50	1,645.69	1.00	1,097.13
1129.875	1.00	1,129.88	1.00	1,129.88
1162.625	1.00	1,162.63	0.00	0.00
1195.375	0.50	597.69	0.00	0.00
1228.125	0.50	614.06	0.00	0.00
1260.875	0.50	630.44	0.00	0.00
1293.625	0.00	0.00	0.00	0.00
Total	**55.50**	**54,995.46**	**84.00**	**56,018.91**

Table 7. Warner-Robins AFB Chiller #6 ton-hours by ton range.

Ton Range	Jul 99		Aug 99	
	Hours	Ton-Hours	Hours	Ton-Hours
16.375	25.50	417.56	22.50	368.44
49.125	0.00	0.00	0.50	24.56
81.875	0.00	0.00	0.00	0.00
114.625	0.00	0.00	0.00	0.00
147.375	0.00	0.00	0.00	0.00
180.125	0.00	0.00	0.00	0.00
212.875	0.00	0.00	0.00	0.00
245.625	0.00	0.00	0.00	0.00
278.375	0.00	0.00	0.00	0.00
311.125	0.00	0.00	0.00	0.00
343.875	0.00	0.00	0.50	171.94
376.625	0.00	0.00	0.00	0.00
409.375	0.00	0.00	0.00	0.00
442.125	0.00	0.00	0.00	0.00
474.875	0.00	0.00	0.00	0.00
507.625	0.00	0.00	0.00	0.00
540.375	0.00	0.00	0.00	0.00
573.125	0.00	0.00	0.00	0.00
605.875	0.00	0.00	0.00	0.00

Ton Range	Jul 99		Aug 99	
	Hours	Ton-Hours	Hours	Ton-Hours
638.625	0.00	0.00	1.00	638.63
671.375	0.00	0.00	0.50	335.69
704.125	0.00	0.00	1.50	1,056.19
736.875	0.00	0.00	6.00	4,421.25
769.625	0.00	0.00	9.50	7,311.44
802.375	0.00	0.00	10.00	8,023.75
835.125	0.00	0.00	20.00	16,702.50
867.875	0.00	0.00	30.00	26,036.25
900.625	0.00	0.00	27.50	24,767.19
933.375	0.00	0.00	47.50	44,335.31
966.125	0.00	0.00	39.50	38,161.94
998.875	1.50	1,498.31	32.00	31,964.00
1031.625	0.50	515.81	26.50	27,338.06
1064.375	1.00	1,064.38	28.00	29,802.50
1097.125	1.50	1,645.69	17.00	18,651.13
1129.875	1.50	1,694.81	18.50	20,902.69
1162.625	1.00	1,162.63	5.00	5,813.13
1195.375	0.50	597.69	1.00	1,195.38
1228.125	1.00	1,228.13	1.00	1,228.13
1260.875	0.50	630.44	0.00	0.00
1293.625	0.00	0.00	0.00	0.00
Total	**34.50**	**10,455.45**	**345.50**	**309,250.10**

Using the full load efficiency of 0.55 kW/ton and the appropriate energy charges, the energy costs are:

For Chiller #5:

Energy cost = 0.55 kW/ton x (54,995.46 ton-hr x $0.03552/kWh + 56,018.91 ton-hr x $0.04932/kWh) = $2,594

For Chiller #6:

Energy cost = 0.55 kW/ton x (10,455.45 ton-hr x $0.03552/kWh + 309,250.10 ton-hr x $0.04932/kWh) = $8,593

The total electrical cost for each new electric chiller for the period would be:

Chiller #5: $2,594 + 0 = $2,594
Chiller #6: $8,593 + 0 = $8,593

The efficiency of the old electric chiller at the central plant was 0.65 kW/ton. Since no demand charges are applied, the demand costs would be zero, regardless of load.

The electrical energy cost would then be:

For Chiller #5:

Energy cost = 0.65 kW/ton x (54,995.46 ton-hr x $0.03552/kWh + 56,018.91 ton-hr x $0.04932/kWh) = $3,066

For Chiller #6:

Energy cost = 0.65 kW/ton x (10,455.45 ton-hr x $0.03552/kWh + 309,250.10 ton-hr x $0.04932/kWh) = $10,155

If the old electric chillers were used, the total electrical cost would then be:

Chiller #5:	$3,066 + 0	=	$3,066
Chiller #6:	$10,155 + 0	=	$10,155

Table 8 summarizes the cost comparison for Warner-Robins AFB. The life cycle economics for Warner-Robins AFB is detailed in the Appendix, and includes parasitic electrical requirements for the chiller.

Table 8. Cost comparison of old vs. new chillers, Warner-Robins AFB.

Chiller Type	Chiller #5	Chiller #6
Old electric chiller	$3,066	$10,155
New electric chiller	$2,594	$8,593
New gas chiller	$1,522 (estimate)	$4,474 (estimate)

4 Conclusion and Recommendations

Conclusion

This study provided performance monitoring data for natural gas cooling technologies operating at two Air Force demonstration facilities, based on the FY99 cooling season. Both theoretical and actual performance values for each natural gas cooling technology were compared for validation of their operation. The technical and economical aspects of operable natural gas cooling equipment performance were monitored on successful commissioning and functional performance testing acceptability. Energy and demand cost analyses were performed to provide a basis for comparison of each natural gas cooling technology with the energy and demand costs of old and new electric chillers.

At the two monitored Air Force bases, the costs for the natural gas used by the engine-driven chillers were lower than electrical costs used by old and new electric chillers, resulting in energy cost savings (Table 3 [p 15] and Table 8 [p 20]).

Hanscom AFB currently has one, 750-ton R-134A York-Caterpillar gas engine-driven chiller under construction at the central plant, Building 1201. The project is scheduled for completion in FY00 due to construction delays.

The engine-driven chiller in a hybrid plant can often be used to reduce or shave the building's electric demand during on-peak hours. One or more electric chillers supply the base cooling load or are shut off during on-peak hours. The savings in peak demand charged by the electric utility can often provide substantial cost savings. Gas cooling can be installed when a significant expansion of a facility is planned, thereby satisfying the need for additional capacity while providing the flexibility to dispatch gas cooling during periods of high electric demand. An example of peak cooling is found in Figure 5.

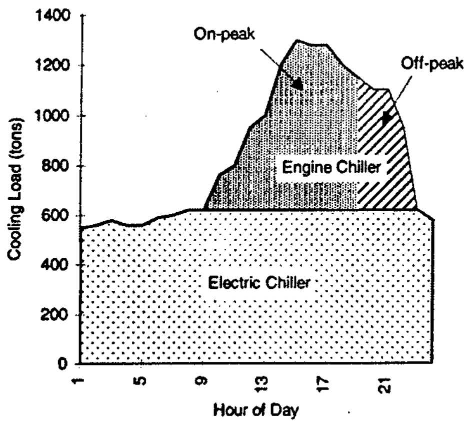

Figure 5. Example of peak shaving curve.
(Source: American Gas Cooling Center, February 1996)

Recommendations

Gas cooling technologies, such as gas engine-driven chillers, can offer installations and bases environmental and economic benefits. The environmental benefit stems from the fact that engine-driven chillers typically use hydrochlorofluorocarbons (HCFCs) or hydrofluorocarbons (HFCs) with low or zero ozone-depleting potential. The economic benefits of engine-driven chillers can vary since gas chiller equipment costs are higher than conventional electric-driven vapor-compression equipment.

To reduce peak electric demand and increase summer gas sales, many gas and electric utilities offer rebates for unit installations and bases on a per-ton basis. Sometimes these rebates alone make up the equipment cost differential. Some gas utilities also offer reduced rates to facilities using gas for cooling purposes. Some applications reduce costs in other areas by providing energy to produce domestic hot water and/or boiler makeup water. Use of these applications increases the system's overall cost effectiveness.

Chillers are rarely operated at their rated capacities more than a few hundred hours per year. Two or more smaller chillers may result in more efficient operation, lower life-cycle costs, and lower operating costs. In some cases, a hybrid chiller plant makes economic sense. A hybrid plant is a combination of electric- and gas engine-driven chillers and sometimes leads to lower life-cycle and operation costs. The operation of the plants would be cycled to take advantage of the off-demand portion of the electric utility bill. The installation of more than one chiller will also allow for continued service during scheduled and unscheduled maintenance (Pedersen et al. 1996).

It is recommended that data points for CHWS and CHWR temperatures and chilled water flow be documented every 15 minutes. To improve performance and acquire a more accurate savings, it is also recommended that each Air Force facility under the Natural Gas Cooling Technology Program provide minute-by-minute readings of natural gas flow, as opposed to instantaneous values every 15 minutes.

In cases where the remote operator is unavailable to download the trend data on a daily basis due to leave or temporary duty (TDY), it is recommended that the proper communications or datalogger software be used to automatically transfer data to the remote operator's computer workstation. Automatic data transfer should occur in the early mornings every 24 hours via modem from the installation's host operator workstation to the remote monitoring site (including weekends and holidays). Without automatic data transfer, the historical trend data provided by the host workstation may not be stored permanently. If the remote operator does not download the trend data in time, valuable data may be lost. Such missing data could compromise the accuracy of performance and cost results.

Finally, it is recommended that CERL representatives be considered to monitor any facilities that will complete successful commissioning and acceptance testing of natural gas cooling equipment for performance to document the actual savings incurred.

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Appendix: Gas Cooling Analysis

Gas Cooling Analysis

Input Data Sheet

< To Print Tables - ctrl t, To Print Charts - ctrl c >

Notice to Users:

This spreadsheet is designed to assist the user in performing a preliminary feasibility analysis comparing electric, absorption, and engine driven chillers. Calculations are based on user provided data and results rely on this input data. This spreadsheet calculates the approximate equipment & installation costs along with the annual operating and maintenance costs. Additionally, simple payback is calculated, based on the incremental additional cost of the alternative cooling technology and the annual operating cost savings. Part of the development of this tool was supported by the Strategic Environmental Research and Development Program (SERDP)

Input Section

Fill in all shaded boxes

Enter Facility Name: Youngstown-Warren REG ARPT

Analyst: WTB, 11/2/99

Cooling Load

Building Type: ~910 Airlift Wing Headquarters

Peak Load:	140	tons
Annual Hours of Operation:	1,732	hours
Equivalent Full Load Hour Percentage:	17	% (for most air conditioning applications, EFLH = 50 %)
Cooling Peak Load/Ave Load Ratio:	29.04	

Chiller Efficiencies:	Peak	IPLV	COP Ratio	Parasitic Electrical Requirements:		
Existing Electric (kW/ton)	0.80	0.80		Existing Elect	0.091	kw/tn
New Electric (kW/ton)	0.70	0.70	1.14 New/Old Elec	New Elect	0.088	kw/tn
Absorption (COP)	0.97	0.97	0.19 Abs/New Elc	Absorption	0.290	kw/tn
Engine Driven (COP)	1.34	1.49	0.27 Gas/New Elc	Eng Driven	0.272	kw/tn

Monthly Peak Cooling Load (% of peak)

Jan	0	Feb	0	Mar	0	Apr	0
May	42	Jun	62	Jul	46	Aug	22
Sep	0	Oct	0	Nov	0	Dec	0

Notes: 1 therm = 100,000 Btu; k = 1000 (kW = 1000 W); M = 1,000,000 (MBtu = 1,000,000 Btu)
When evaluating steam fired absorption chillers, be sure to account for boiler efficiency when entering chiller COP. This is not done automatically.

Gas Cooling Analysis

Input Data Sheet

Facility: Youngstown-Warren REG ARPT

Utility Rates

Notes: Water Cooled Recip.

Engine waste heat considers both exhaust gases and cooling jacket water
If boiler fuel not gas, convert $/MBtu to $/therm
Can not calculate winter type ratchet charges; input directly??
Must use month format Xxx (i.e Jan, Feb)

Natural Gas Utility Rates:

Cooling Rate	0.434	$/therm				
Boiler Rate	0.434	$/therm				
Elect/Gas Use Cost Ratio	2.50					
Electric Utility Rates:						
Summer Demand	18.36	$/kW	from	Jan	through	Dec
Ratchet	0	%	from	Jan	through	Dec
Winter Demand	18.36	$/kW	Demand$/Use$ Ratio (hrs)			
Energy	0.037	$/kWh	Smr. El/Gas:	1,241	Wntr El/Gas:	1,241

NOTE: Review demand charge calculations to determine appropriate values to enter for number of applicable months.

NOTE: The above rates should include any applicable taxes and surcharges.

Equipment Cost

	Chiller $/ton	Rebate $/ton	Installation $/ton	Maintenance	
Electric (existing)				0.008	$/ton-hr
Electric (new)	270	0	375	0.006	$/ton-hr
Absorption	950	0	415	0.0085	$/ton-hr
Engine Driven					
w/o heat recovery	645	0	829	0.012	$/ton-hr
w/ heat recovery	710	0	912	0.013	$/ton-hr

Heat Recovery

(Engine Driven Chiller only)

Engine Waste Heat

Useful thermal energy	0	Btu/hr	Engine efficiency	35	%
Summer boiler efficiency	80	%	Recoverable percent	75	%
			Max avail thermal energy	549,664	Btu/hr

Gas Cooling Analysis

Output Data Sheet

Facility: Youngstown-Warren REG ARPT

Existing Electric Chiller Energy Costs

Chiller Peak Efficiency: 0.8 kW/ton

Chiller IPLV (seasonal efficiency): 0.8 kW/ton (see note below)

Energy Charge (chiller):	140	tons	x	0.800	kW/ton (IPLV)	x	302	EFLH	x	0.037	$/kWh	=	$1,250
Energy Charge (parasitic):	140	tons	x	0.091	kW/ton	x	1,732	operating hr	x	0.037	$/kWh	=	$819
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)											=	$3,529
											Total Annual Energy Cost		$5,598

New Electric Chiller Energy Costs

Chiller Peak Efficiency: 0.7 kW/ton

Chiller IPLV (seasonal efficiency): 0.7 kW/ton (see note below)

Energy Charge (chiller):	140	tons	x	0.700	kW/ton (IPLV)	x	302	EFLH	x	0.037	$/kWh	=	$1,094
Energy Charge (parasitic):	140	tons	x	0.088	kW/ton	x	1,732	operating hr	x	0.037	$/kWh		$787
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)											=	$3,087
											Total Annual Energy Cost		$4,968

Absorption Chiller Energy Costs

Chiller Peak Efficiency: 0.97 COP

Chiller IPLV (seasonal efficiency): 0.97 COP -or- 0.124 therms/ton-hr (see note below)

Incremental Parasitic Power Consumption: 0.29 kW/ton (see note below)

Gas Charge:	140	tons	x	0.124	therms/ton-hr	x	302	EFLH	x	0.434	$/therm	=	$2,266
Energy Charge (parasitic):	140	tons	x	0.290	kW/ton	x	1,732	operating hr	x	0.037	$/kWh	=	$2,602
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)											=	$2,982
											Total Annual Energy Cost		$7,849

Engine Driven Chiller Energy Costs

Chiller Peak Efficiency: 1.34 COP

Chiller IPLV (seasonal efficiency): 1.49 COP -or- 0.081 therms/ton-hr (see note below)

Incremental Parasitic Power Consumption: 0.2715 kW/ton (see note below)

Heat Recovery: 0,000 BTU/hr

Boiler Efficiency: 80%

Gas Charge:	140	tons	x	0.081	therms/ton-hr	x	302	EFLH	x	0.434	$/therm	=	$1,475
Energy Charge (parasitic):	140	tons	x	0.272	kW/ton	x	1,732	operating hr	x	0.037	$/kWh	=	$2,436
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)											=	$2,791
											Total Annual Energy Cost (without heat recovery)		$6,702
Savings with Optional Heat Recovery:		Btu/hr	x	1	therm/100,000 Bt	x	302	EFLH	x	0.434	$/therm / 80 % boiler efficiency	=	
											Total Annual Energy Cost (with heat recovery)		$6,702

EFLH = Equivalent Full Load Hours (for most air conditioning applications, EFLH = 0.5 x annual hours of operation)

IPLV = Integrated Part Load Value. The IPLV should be used for all seasonal energy calculations, since is it represents the seasonal average (non-full load) operating efficiency of the chiller.

therms/ton*hr = 12,000 Btu/hr/ton / (100,000 Btu/therm x COP [Btu/hr Cooling / Btu/hr input])

Direct-fired absorption chillers have significantly higher electric parasitic consumption than electric chillers. This is due to greater condenser flow rates, heat rejection, and pressure drops in the heat exchangers. Engine driven chillers have slightly higher parasitics than electric chillers due to the engine heat rejection.

Gas Cooling Analysis

Output Data Sheet

Facility: Youngstown-Warren REG ARPT

Month	Demand Charge ($/kW)	Existing Electric Chiller		New Electric Chiller		Absorption Chiller		Engine Driven Chiller	
		Billed Demand (kW)	Monthly Charge ($)	Billed Demand (kW)	Monthly Charge ($)	Billed Demand (kW)	Monthly Charge ($)	Billed Demand (kW)	Monthly Charge ($)
Jan	18.36								
Feb	18.36								
Mar	18.36								
Apr	18.36								
May	18.36	47	865	41	757	41	745	38	698
Jun	18.36	64	1,170	55	1,015	41	745	38	698
Jul	18.36	51	930	44	812	41	745	38	698
Aug	18.36	31	564	27	503	41	745	38	698
Sep	18.36								
Oct	18.36								
Nov	18.36								
Dec	18.36								
Ave/Sum		16	3,529	14	3,087	14	2,982	13	2,791

Monthly Demand Charge ($/kW) is determined from the utility rate structure or utility contract.
Billed Demand ($) is calculated based on the utility rate structure. If there is no Ratchet associated with the demand charge, the Billed Demand equals the peak metered demand which occured during that month.
If the utility rate structure has a Ratchet clause, the Billed Demand is equal to the greater of either the actual peak metered demand or the peak demand multiplied by the Ratchet percentage.
Monthly Charge ($) is calculated by multiplying the Monthly Demand Charge by the Billed Demand.
The Annual Average/Sum is the average of the monthly Billed Demands and the sum of the Monthly Demand Charges for each of the chiller technologies.
The actual meter demand is the sum of the peak output of the chiller during the month in question plus the full kW rating of the parasitic equipment, i.e. the evaporator and condenser water pumps and cooling tower fan motors.

Gas Cooling Analysis

Output Data Sheet

Facility: Youngstown-Warren REG ARPT

Maintenance Costs

	EFLH		Capacity		Rate		Maintenance Costs	Annual Operating Costs (Energy + Maintenance)
Electric Chiller Maintenance Costs								
Existing	301.64166 EFLH	x	140 tons	x	0.008 $/ton-hr	=	$338	$5,936
New	301.64166 EFLH	x	140 tons	x	0.006 $/ton-hr	=	$253	$5,221
Absorption Chiller Maintenance Costs								
	301.64166 EFLH	x	140 tons	x	0.0085 $/ton-hr		$359	$8,208
Engine Driven Chiller Maintenance Costs								
w/o heat recovery	301.64166 EFLH	x	140 tons	x	0.012 $/ton-hr		$507	$7,209
w/ heat recovery	301.64166 EFLH	x	140 tons	x	0.013 $/ton-hr		$549	$7,251

System Installed Cost

	Equipment Cost			+	Installation Cost			=	Installed Cost	Utility Rebate	Cost Premium	Incremental Simple Payback
Electric Chiller Installed Costs												
	270 $/ton	x	140 tons	+	375 $/ton	x	140 tons	=	$90,300		$0	basecase
Absorption Chiller Installed Costs												
	950 $/ton	x	140 tons	+	415 $/ton	x	140 tons	=	$191,100		$100,800	NEVER
Engine Driven Chiller Installed Costs												
w/o heat recovery	645 $/ton	x	140 tons	+	829 $/ton	x	140 tons	=	$206,360		$116,060	NEVER
w/ heat recovery	710 $/ton	x	140 tons	+	912 $/ton	x	140 tons	=	$227,080		$136,780	NEVER

Annual Operating Cost = Annual Energy Cost + Annual Maintenance Cost
Installed Cost = Chiller Cost per Ton * Capacity + Installation Cost per Ton * Chiller Capacity
Cost Premium = Installed cost of a specific chiller type - Installed cost of an electric chiller
Incremental Simple Payback = Cost Premium/(Electric Chiller Annual Operating Cost - Specific Chiller Annual Operating Cost)

Gas Cooling Analysis

Input Data Sheet

< To Print Tables - ctrl t, To Print Charts - ctrl c >

Notice to Users:

This spreadsheet is designed to assist the user in performing a preliminary feasibility analysis comparing electric, absorption, and engine driven chillers. Calculations are based on user provided data and results rely on this input data. This spreadsheet calculates the approximate equipment & installation costs along with the annual operating and maintenance costs. Additionally, simple payback is calculated, based on the incremental additional cost of the alternative cooling technology and the annual operating cost savings. Part of the development of this tool was supported by the Strategic Environmental Research and Development Program (SERDP)

Input Section

Fill in all shaded boxes

Enter Facility Name: Warner-Robins AFB, CEP

Analyst: WTB 11/4/99

Cooling Load

Building Type: Central Plant (Chiller #6)

Peak Load:	1,310	tons
Annual Hours of Operation:	380	hours
Equivalent Full Load Hour Percentage:	82	% (for most air conditioning applications, EFLH = 50 %)
Cooling Peak Load/Ave Load Ratio:	28.09	

Chiller Efficiencies:	Peak	IPLV	COP Ratio		Parasitic Electrical Requirements:		
Existing Electric (kW/ton)	0.65	0.65			Existing Elect	0.240	kw/tn
New Electric (kW/ton)	0.55	0.55	1.18	New/Old Elec	New Elect	0.240	kw/tn
Absorption (COP)	1.02	1.02	0.16	Abs/New Elc	Absorption	0.315	kw/tn
Engine Driven (COP)	1.83	2.37	0.29	Gas/New Elc	Eng Driven	0.255	kw/tn

Monthly Peak Cooling Load (% of peak)

Jan	0	Feb	0	Mar	0	Apr	0
May	0	Jun	0	Jul	95	Aug	94
Sep	0	Oct	0	Nov	0	Dec	0

Notes: 1 therm = 100,000 Btu; k = 1000 (kW = 1000 W); M = 1,000,000 (MBtu = 1,000,000 Btu)
When evaluating steam fired absorption chillers, be sure to account for boiler efficiency when entering chiller COP. This is not done automatically.

Gas Cooling Analysis

Input Data Sheet

Facility: Warner-Robins AFB, CEP

Utility Rates

Notes:
- Centrifugal Water Cooled, NG and Elec
- Plant already has (2) 1500 and (1) 750 ton electric units
- Using report parasitic estimates
- Base loaded Chiller (100% year round)
- Engine waste heat considers both exhaust gases and cooling jacket water
- If boiler fuel not gas, convert $/MBtu to $/therm
- Can not calculate winter type ratchet charges; input directly??
- Must use month format Xxx (i.e Jan, Feb)

Natural Gas Utility Rates:

Cooling Rate	0.216	$/therm				
Boiler Rate	0.216	$/therm				
Elect/Gas Use Cost Ratio	5.19					

Electric Utility Rates:

Summer Demand	0.00	$/kW	from	Mar	through	Sep
Ratchet	95	%	from	Jan	through	Dec
Winter Demand	0.00	$/kW	Demand$/Use$ Ratio (hrs)			
Energy	0.038	$/kWh	Smr. El/Gas:	0	Wntr El/Gas:	0

NOTE: Review demand charge calculations to determine appropriate values to enter for number of applicable months.

NOTE: The above rates should include any applicable taxes and surcharges.

Equipment Cost

	Chiller $/ton	Rebate $/ton	Installation $/ton	Maintenance	
Electric (existing)				0.008	$/ton-hr
Electric (new)	418	0	387	0.006	$/ton-hr
Absorption	672	0	402	0.0085	$/ton-hr
Engine Driven					
w/o heat recovery	577	0	328	0.012	$/ton-hr
w/ heat recovery	606	0	407	0.013	$/ton-hr

Heat Recovery

(Engine Driven Chiller only)

			Engine Waste Heat		
Useful thermal energy	0	Btu/hr	Engine efficiency	35	%
Summer boiler efficiency	80	%	Recoverable percent	75	%
			Max avail thermal energy	3,236,412	Btu/hr

Gas Cooling Analysis

Output Data Sheet

Facility: Warner-Robins AFB, CEP

Existing Electric Chiller Energy Costs

Chiller Peak Efficiency: 0.65 kW/ton

Chiller IPLV (seasonal efficiency): 0.65 kW/ton (see note below)

Energy Charge (chiller):	1,310	tons	x	0.650	kW/ton (IPLV)	x	312	EFLH	x	0.038	$/kWh	=	$10,155
Energy Charge (parasitic):	1,310	tons	x	0.240	kW/ton	x	380	operating hr	x	0.038	$/kWh	=	$4,569
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)											=	
											Total Annual Energy Cost		$14,723

New Electric Chiller Energy Costs

Chiller Peak Efficiency: 0.55 kW/ton

Chiller IPLV (seasonal efficiency): 0.55 kW/ton (see note below)

Energy Charge (chiller):	1,310	tons	x	0.550	kW/ton (IPLV)	x	312	EFLH	x	0.038	$/kWh	=	$8,593
Energy Charge (parasitic):	1,310	tons	x	0.240	kW/ton	x	380	operating hr	x	0.038	$/kWh		$4,569
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)											=	
											Total Annual Energy Cost		$13,161

Absorption Chiller Energy Costs

Chiller Peak Efficiency: 1.02 COP

Chiller IPLV (seasonal efficiency): 1.02 COP -or- 0.118 therms/ton-hr (see note below)

Incremental Parasitic Power Consumption: 0.315 kW/ton (see note below)

Gas Charge:	1,310	tons	x	0.118	therms/ton-hr	x	312	EFLH	x	0.216	$/therm	=	$10,382
Energy Charge (parasitic):	1,310	tons	x	0.315	kW/ton	x	380	operating hr	x	0.038	$/kWh	=	$5,996
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)											=	
											Total Annual Energy Cost		$16,378

Engine Driven Chiller Energy Costs

Chiller Peak Efficiency: 1.83 COP

Chiller IPLV (seasonal efficiency): 2.37 COP -or- 0.051 therms/ton-hr (see note below)

Incremental Parasitic Power Consumption: 0.255 kW/ton (see note below)

Heat Recovery: 0,000 BTU/hr Boiler Efficiency: 80%

Gas Charge:	1,310	tons	x	0.051	therms/ton-hr	x	312	EFLH	x	0.216	$/therm	=	$4,472
Energy Charge (parasitic):	1,310	tons	x	0.255	kW/ton	x	380	operating hr	x	0.038	$/kWh	=	$4,854
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)											=	
											Total Annual Energy Cost (without heat recovery)		$9,326
Savings with Optional Heat Recovery:		Btu/hr	x	1	therm/100,000 Bt	x	312	EFLH	x	0.216	$/therm / 80 % boiler efficiency	=	
											Total Annual Energy Cost (with heat recovery)		$9,326

EFLH = Equivalent Full Load Hours (for most air conditioning applications, EFLH = 0.5 x annual hours of operation)

IPLV = Integrated Part Load Value. The IPLV should be used for all seasonal energy calculations, since is it represents the seasonal average (non-full load) operating efficiency of the chiller.

therms/ton*hr = 12,000 Btu/hr/ton / (100,000 Btu/therm x COP [Btu/hr Cooling / Btu/hr input])

Direct-fired absorption chillers have significantly higher electric parasitic consumption than electric chillers. This is due to greater condenser flow rates, heat rejection, and pressure drops in the heat exchangers. Engine driven chillers have slightly higher parasitics than electric chillers due to the engine heat rejection.

Gas Cooling Analysis

Output Data Sheet

Facility: Warner-Robins AFB, CEP

Month	Demand Charge ($/kW)	Existing Electric Chiller Billed Demand (kW)	Existing Electric Chiller Monthly Charge ($)	New Electric Chiller Billed Demand (kW)	New Electric Chiller Monthly Charge ($)	Absorption Chiller Billed Demand (kW)	Absorption Chiller Monthly Charge ($)	Engine Driven Chiller Billed Demand (kW)	Engine Driven Chiller Monthly Charge ($)
Jan		1,108		983		392		317	
Feb		1,108		983		392		317	
Mar		1,108		983		392		317	
Apr		1,108		983		392		317	
May		1,108		983		392		317	
Jun		1,108		983		392		317	
Jul		1,110		985		413		334	
Aug		1,108		983		413		334	
Sep		1,108		983		392		317	
Oct		1,108		983		392		317	
Nov		1,108		983		392		317	
Dec		1,108		983		392		317	
Ave/Sum		1,108		983		395		320	

Monthly Demand Charge ($/kW) is determined from the utility rate structure or utility contract.
Billed Demand ($) is calculated based on the utility rate structure. If there is no Ratchet associated with the demand charge, the Billed Demand equals the peak metered demand which occured during that month.
If the utility rate structure has a Ratchet clause, the Billed Demand is equal to the greater of either the actual peak metered demand or the peak demand multiplied by the Ratchet percentage.
Monthly Charge ($) is calculated by multiplying the Monthly Demand Charge by the Billed Demand.
The Annual Average/Sum is the average of the monthly Billed Demands and the sum of the Monthly Demand Charges for each of the chiller technologies.

Gas Cooling Analysis

Output Data Sheet

Facility: Warner-Robins AFB, CEP

Maintenance Costs

							Maintenance Costs	Annual Operating Costs (Energy + Maintenance)
Electric Chiller Maintenance Costs								
Existing	311.866 EFLH	x	1310 tons	x	0.008 $/ton-hr	=	$3,268	$17,992
New	311.866 EFLH	x	1310 tons	x	0.006 $/ton-hr	=	$2,451	$15,612
Absorption Chiller Maintenance Costs								
	311.866 EFLH	x	1310 tons	x	0.0085 $/ton-hr		$3,473	$19,851
Engine Driven Chiller Maintenance Costs								
w/o heat recovery	311.866 EFLH	x	1310 tons	x	0.012 $/ton-hr		$4,903	$14,229
w/ heat recovery	311.866 EFLH	x	1310 tons	x	0.013 $/ton-hr		$5,311	$14,637

System Installed Cost

	Equipment Cost				Installation Cost				Installed Cost	Utility Rebate	Cost Premium	Incremental Simple Payback
Electric Chiller Installed Costs												
	418 $/ton	x	1310 tons	+	387 $/ton	x	1310 tons	=	$1,054,550		$0	basecase
Absorption Chiller Installed Costs												
	672 $/ton	x	1310 tons	+	402 $/ton	x	1310 tons	=	$1,406,940		$352,390	NEVER
Engine Driven Chiller Installed Costs												
w/o heat recovery	577 $/ton	x	1310 tons	+	328 $/ton	x	1310 tons	=	$1,185,550		$131,000	94.7 yrs
w/ heat recovery	606 $/ton	x	1310 tons	+	407 $/ton	x	1310 tons	=	$1,327,030		$272,480	279.4 yrs

Annual Operating Cost = Annual Energy Cost + Annual Maintenance Cost
Installed Cost = Chiller Cost per Ton * Capacity + Installation Cost per Ton * Chiller Capacity
Cost Premium = Installed cost of a specific chiller type - installed cost of an electric chiller
Incremental Simple Payback = Cost Premium/(Electric Chiller Annual Operating Cost - Specific Chiller Annual Operating Cost)

Abbreviations and Acronyms

AFB	Air Force Base
AFCESA	Air Force Civil Engineer Support Agency
ANG	Air National Guard
ARS	Air Reserve Station
Btu	British thermal unit
CERL	Construction Engineering Research Laboratory
CFC	chlorofluorocarbon
CHW	chilled water
CHWR	chilled water return
CHWS	chilled water supply
COP	coefficient of performance
DDC	direct digital control
deg F	degrees Fahrenheit
DOD	Department of Defense
FY	fiscal year
gpm	gallons per minute
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
HHV	higher heating value
kW	kilowatt
kWh	kilowatt-hour
MBtu	million British thermal units
SCF	standard cubic feet
SCFH	standard cubic feet per hour
TDY	temporary duty

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High-efficiency gas-fired cooling equipment is readily available for commercial, institutional, and industrial facilities. Natural gas engine-driven chillers have higher coefficients of performance than any other natural gas cooling system, and can serve as energy efficient alternatives for new electric chillers. This study monitored the performance of natural gas cooling technologies operating at two Air Force bases during the fiscal year 1999 cooling season and compared the actual performance data to theoretical values.

Energy and demand cost analyses were performed to compare each natural gas cooling technology with the energy and demand costs of old and new electric chillers. The study determined that, at the monitored bases, the costs for the natural gas used by the engine-driven chillers were lower than electrical costs used by old and new electric chillers, resulting in an energy cost savings.

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